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Static Stress-strain Analyses of Embankment Dam with Asphalt Core

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Abstract: Gabric dam which is placed at Hormozgan, Iran has height of 41 m and is placed on an alluvium layer with 13 m thickness. One of the design alternatives for this construction is embankment dam with asphalt core. Regarding to design condition, the asphaltic core has been placed over alluvium foundation and cutoff wall has been contrived for seepage control. Whereas the asphaltic core posed over cutoff wall and shell posed over alluvium foundation, unsymmetric settlements at constructions was expected during construction and sluicing periods which can affect the behavior of asphaltic core. In order to obtain a clear understanding of this behavior, two dimensional finite element analyses have been performed and different contours for stresses and displacements have been presented. Due to obtained results the effect of core deformation modulus, stiffness of coarse grain alluvial foundation and removal of fine grain alluvial on principle stresses, principle shear stresses and vertical and horizontal strains have been investigated. Also, vertical stress distribution at the end of construction and vertical and horizontal displacements after sluicing have been studied. Results show that vertical stress values in asphaltic core reach two times of overburden pressure that indicates considerable load transfer to asphaltic core and maximum vertical displacement of asphaltic core in the end of construction was 0.22 m while horizontal displacement of asphaltic core is negligible. Also, the results reveal that removal of alluvial layer from beneath of down-stream shell will not assist adjustment of stresses and strains in core.

Key words: Gabric dam, asphaltic core, finite element method, static analysis, alluvial foundation

INTRODUCTION

Dams with concrete asphaltic core are one of important options in designing embankment and rock fill dams, especially in areas that suffer from lack of fine grain materials with good quality and appropriate quantity for constructing clay core dams. Advantages of this kind of dams are lack of crack and appropriate impediment, not being sensitive to different climate conditions, sluicing during construction, self-repairing capacity of core material, flexibility and deformability, durability and resistance against continuous seepage, relative resistance against earthquake and high security in war conditions. Several cases of this type of dam have been constructed over the world. Lefebvre and Duncan (1974) studied some of the factors leading to transverse cracking in low-embankment dams using finite element analysis. The factors studied were the analysis procedure, gravity turn-on or construction sequence, the magnitude and time of occurrence of the settlement of the dam, the stress-strain characteristics of the dam material and the shape of the abutment profile. Chugh (1983) conducted one-dimensional wave propagation method for earthquake response analysis of horizontally-layered sites of infinite lateral extent is adapted to account for the finite cross-sectional dimensions of an embankment dam overlying a foundation deposit which may be considered infinite in its lateral extent. A two-dimensional dynamic finite element analysis was also performed for that case. The comparisons of computed and observed responses support the modified use of the simple numerical procedure. Zhao *et al*. (1993) carried out a systematic investigation into the effect of both the type of impervious members and the reservoir bottom sediment on the dynamic response of embankment dams using the finite and infinite element coupled method. Tancev and Kokalanov (1995) developed an incremental, nonlinear finite element procedure, suitable for deformation, stress and stability analysis of embankment dams with waterproof elements other than earth. The procedure was applied for analysis of hypothetical rock-fill dams with asphaltic facing and an internal asphaltic core -vertical and inclined. Studies were carried out to understand the prototype behavior of these types of rock-fill dams. Both rock-fill and asphalt behavior was modeled by using hyperbolic relations. Akkose *el al*. (2007) studied stochastic seismic response of a rock-fill dam by finite element method. The Keban dam constructed in Elazig, Turkey was chosen as a numerical example. The interaction of the rock-fill dam with the reservoir was

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neglected, but not the foundation rock. Tanaka (2007) studied the elasto-plastic and viscoplastic constitutive relations with kinematic strain hardening-softening model. A generalized return-mapping algorithm was applied to solution methods of the problems. The dynamic relaxation method for static problems and the dynamic analysis for earthquake responses were solved based on finite element methods. Moayed and Ramzanpour (2008) studied the dynamic behavior of a zoned core earth-fill dam which due to lack of suitable clay materials, the dam was designed as zoned core that was composed of three vertical zones including Central Lean (CL) clay core and two sides clayey Gravel Layers (GC). Seismic behavior of dam was analyzed in two cases including homogenous clayey core and zoned core by finite element method. The results showed that the displacements, accelerations and spectral response in simple core are more than zoned core. Tsompanakis *et al*. (2009) focused on the simulation of the seismic response of a typical embankment using artificial neural networks. The dynamic response of the embankment was evaluated utilizing the finite-element method, where the nonlinear behavior of the geo-materials can be taken into account by an equivalent-linear procedure.

In this study finite element analyses have been performed in order to investigate the behavior of Gabric embankment dam with asphaltic core which is located at Hormozgan, Iran with 41 m height and 13 m thickness and is placed over alluvial bed, during construction and sluicing stages. Asphaltic core has been located over alluvial foundation and under it cutoff wall for controlling seepage of water in foundation been considered. Locating asphaltic core over cutoff wall and also dam's shell on alluvial foundation could cause asymmetric seepage during construction and sluicing stages that can affects behavior of dam’s body. Foundation of dam consists of two layers; overlaying layer is silty sand and located higher than river’s level. Underlying layer is a mixture of silty sand and gravel that are under river's level. However, during construction, higher layer in up-stream has been removed completely, while in down-stream it was removed partially. Also, the effect of core’s deformation modulus, stiffness of coarse grain alluvial foundation materials and amount of remove of fine grain alluvial on the results has been investigated too.

GEOMETRY OF MODEL

Due to geometrical characteristics of dam’s location, plane strain condition in maximum cross section of dam is modeled with acceptable approximation (Fig. 1). This section has maximum height of asphaltic core and alluvial thickness. Displacement of bed rocks in all analyses are considered zero.

ANALYSIS METHOD

Gabric dam placed on Gabric River at Hormozgan, Iran has height of 41 m and is placed on an alluvium layer with 13 m thickness. Dam’s construction started in 2003 and finished in 2009. Static finite element analysis by assuming linear behavior for core material and cutoff wall and also non-linear behavior for other material in plane strain condition has been conducted. In this method, locating of dam construction and sluicing reservoir has been considered step by step. Figure 2 shows the meshing plan of the model.

MATERIAL PROPERTIES

Because of limitation of strain values in asphaltic core, linear elastic behavior with acceptable approximation could be assumed for core’s materials (Adikari *et al*., 1988) For estimation of behavioral parameters of core’s material,

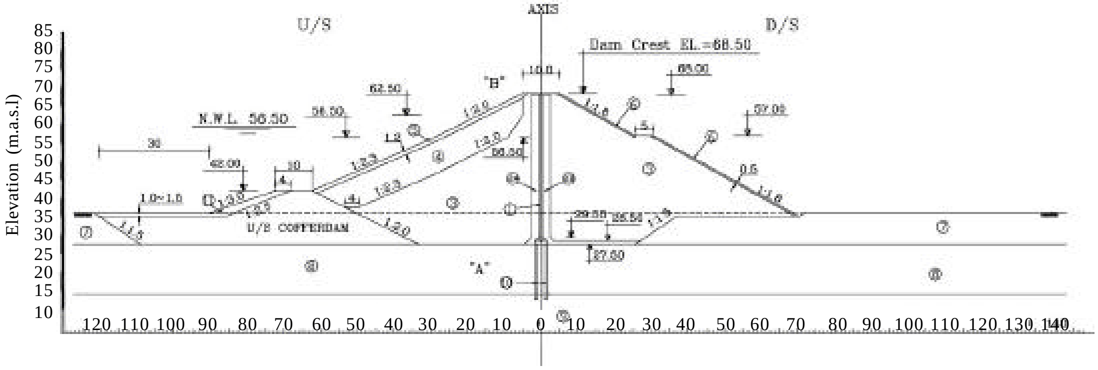

Fig. 1: Gabric dam section

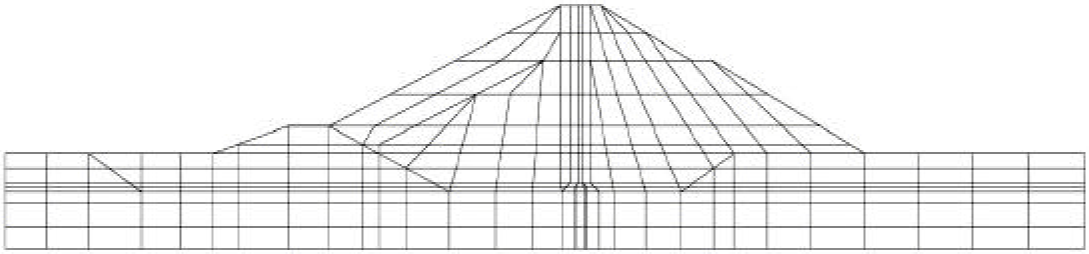

Fig. 2: Finite element model of the dam

offered values of previous studies have been used (Hoeg, 1993). Also, for investigating the effect of changes in deformable modulus, analysis has been conducted for both 100 and 250 MPa deformation modulus. In both cases, passion's ratios were 0.49. Cutoff wall also modeled as linear elastic which elastic parameters have been selected based on (ICOLD, 1985) offering from material characteristic of alluvial foundation. Behavior of other material including rock fill and shells, transition zones in up-stream and down-stream parts of core, fine and coarse grain alluvial foundation have been estimated by non-linear hyperbolic model. For studying the effect of stiffness of alluvial foundation material on stresses and strains of asphaltic core, three different values for elastic modulus parameter of core in hyperbolic model have been considered that were K = 200, 400 and 600.

RESULTS

Stresses distribution and load transfer in various parts of dam's body, lateral strain values in asphaltic core and occurrence of shear and tensile failure in asphaltic core have been presented.

Stress distribution: Vertical stress distribution in the end of dam construction has been shown in Fig. 3. In vertical stress distribution, strong increase in transition from shell and transition layers toward asphaltic core are observed which is because of considerable difference between stiffness and deformation modulus of asphaltic core and sand and gravel shell that leads to non-equal settlement of them and loading transfer from shell to core. Vertical stress values in asphaltic core reach two times of overburden pressure that indicates considerable load transfer to asphaltic core.

Displacements distribution: Displacements distribution of dam's body and foundation in the end of construction has been shown in Fig. 4 and 5. In Fig. 4, vertical displacement contours in the end of construction have been depicted. Maximum settlement occurs in the middle of height at down-stream shell and adjacent to transition zone that is equal to 0.28 m and decrease rapidly toward slopes. Asymmetric vertical settlement distribution in up-stream and down-stream shell is associated with asymmetric material characteristics and dam's geometry. Horizontal displacement distribution in the end of dam's construction has been shown in Fig. 5. Maximum horizontal displacement occurred in down-stream shell and is equal to 0.18 m downward. Maximum horizontal displacement in up-stream shell is equal to 0.08 m. Overall, horizontal displacement of dam in the end of construction has relatively small values and indicates the stable situation at this condition. Horizontal displacements after sluicing have been depicted in Fig. 6. In this condition points' shift is toward downward and maximum horizontal displacement in down-stream shell is equal to 0.24 m. Maximum vertical displacement of asphaltic core in the end of construction was 0.22 m. Horizontal displacement of asphaltic core in this case is negligible, while after sluicing it reaches 0.14 m in dam's crown.

Control of failure and lateral strain in core: Lateral strain values in asphaltic core elements in various cases have been shown in Fig. 7a-d. As it could be seen, lateral strain values in core reaches 1.2%, thus there are no problems due to change in permeability value. Maximum of shear stress values in asphaltic core in various cases has been shown in Fig. 8a-c. Possibility of shear or tensile failure in asphaltic core after sluicing due to results of compacted asphaltic core material is low. Hoeg (1993) obtained similar results for shear or tensile failure in asphaltic core.

Effect of core's deformation modulus: As mentioned before, for estimation of behavioral parameters of core's materials, offered values from previous researchers in similar projects have been used. Thus, analyses have been conducted by two deformation values: 100 and 250 Mpa. Obtained results include changes of stress and strain values and also displacements in core have been investigated.

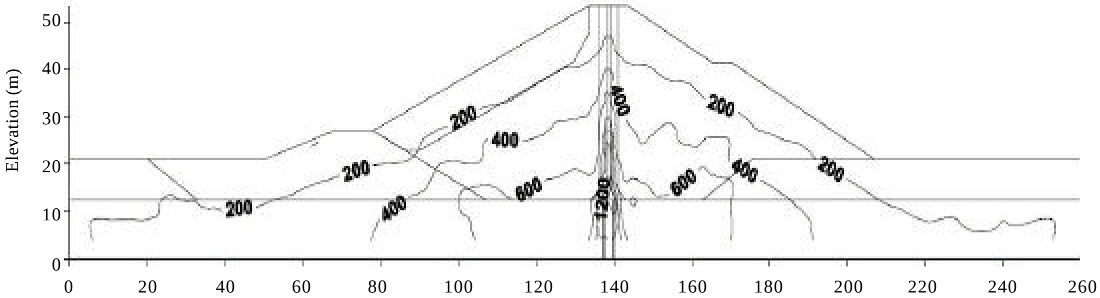

Fig. 3: Vertical stress contour in the end of construction

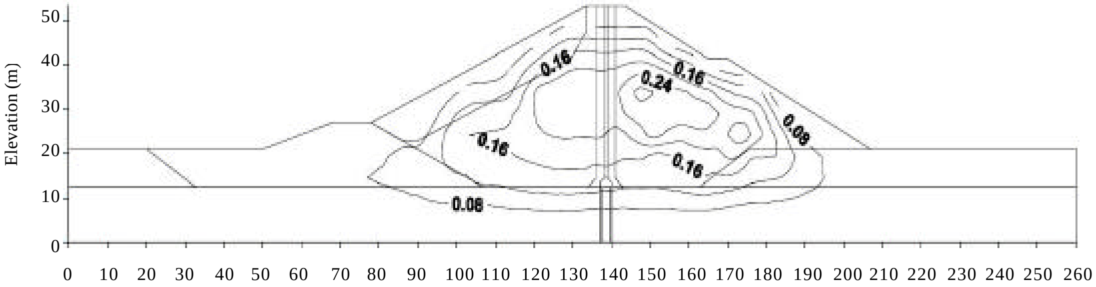

Fig. 4: Vertical displacement contour in the end of construction

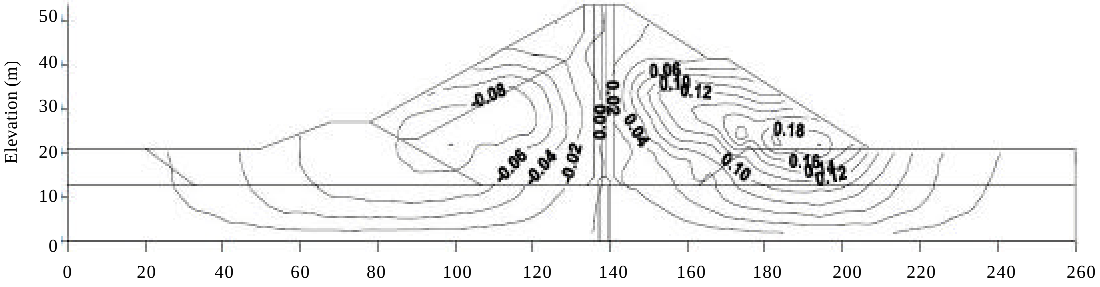

Fig. 5: Horizontal displacement contour in the end of construction

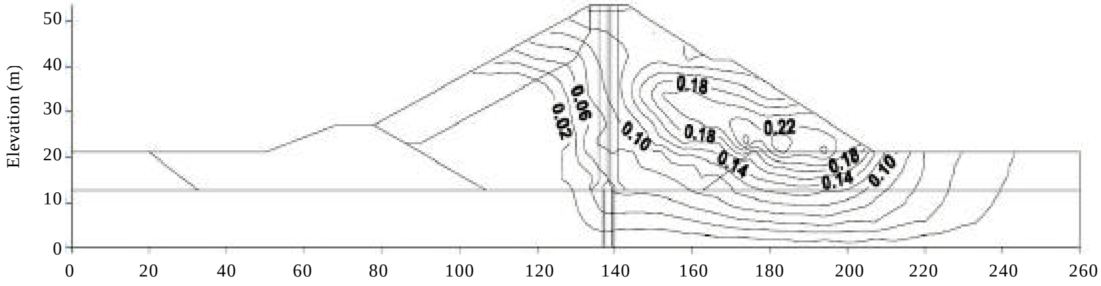

Fig. 6: Horizontal displacement contour after sluicing

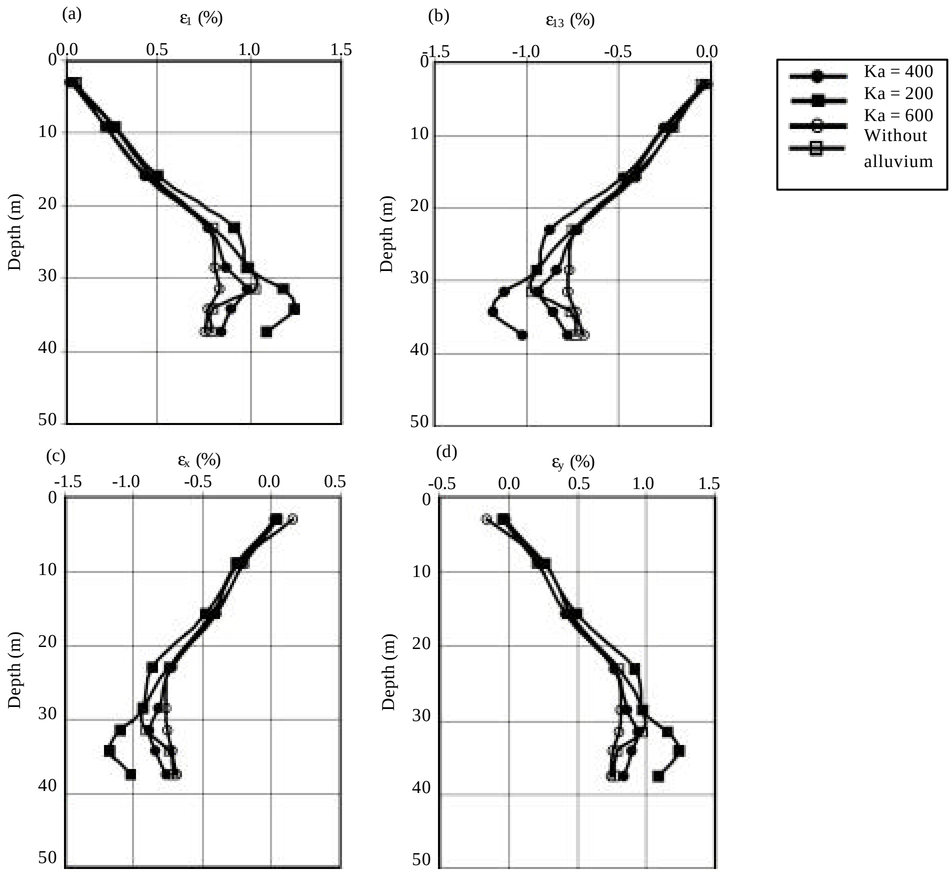

Fig. 7: (a-d) Variation of lateral strains in asphaltic corefig

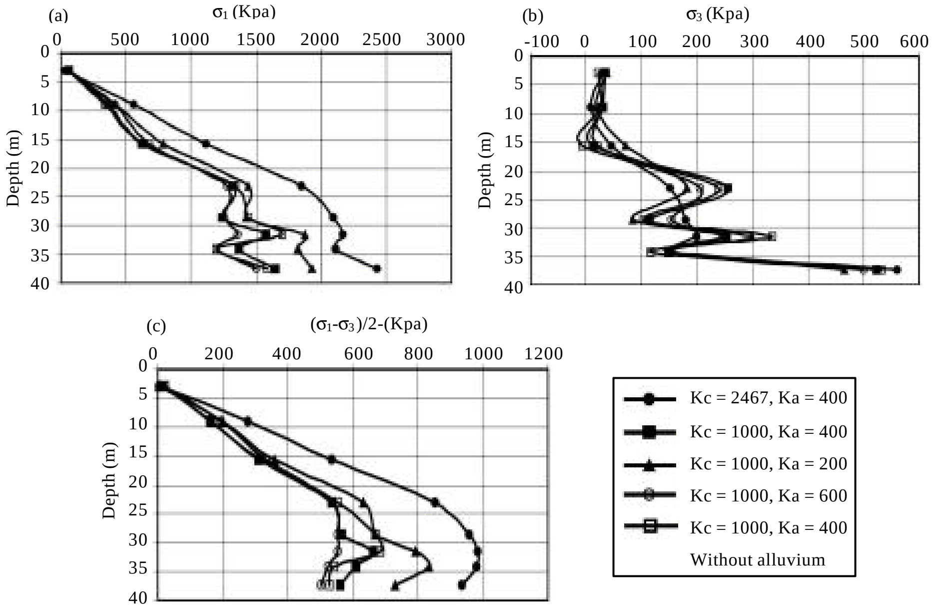

Fig. 8: (a-c) Variation of stress in asphaltic core after sluicing

As it could be seen in Fig. 8, with increase in stiffness of core material, maximum principle stress in all point of core in depth has been increased that indicates more absorption of stress by asphaltic core. Also by increasing of stiffness of core material, maximum shear stress value in all points of core has been increased. In both cases, maximum shear stress values in asphaltic core show that the possibility of shear failure in core is very low. By studying vertical and horizontal strains in core, it can be concluded that by decreasing the stiffness of core material, vertical and horizontal strain would increase, although in all cases horizontal strain values reached 1.2% and as a result, asphaltic core after deformation remains impermeable.

Effect of fine grain alluvial removal in down-stream of dam: One of important issues from economical point of view is the amount of alluvial removal. For this purpose, several analyses for studying the effect of removal of fine grain alluvia on results have been conducted. As it has been presented in Fig. 7 and 8, principally, total fine grain alluvial removal from beneath of down-stream shell has no effect on the amount of strain and stress in asphaltic core. Thus, removal of alluvial from beneath of down-stream shell will not assist adjustment of stresses and strains in core.

Effect of alluvial foundation's stiffness: The most important issue in stress-strain behavior of Gabric dam is considering the presence of alluvial foundation in stress and strain values in asphaltic core. Therefore, hyperbolic modulus parameter (K) for alluvial foundation within 200 - 600 m has been considered. In Fig. 8 stress variation in asphaltic core after sluicing in various states has been offered. As it could be seen, stress values in approximate depth of 20 m from dam's crown (middle of dam's height) in different states of alluvial foundation is approximately equal, but in depth deeper than 20 m (lower part of the dam) with decrease of stiffness of alluvial foundation, maximum principle stress values and shear stresses in asphaltic core elements has been increased. In Fig. 7, strain changes in asphaltic core after sluicing for different stiffness of alluvial foundation has been presented. As could be observed strain values in upper part of the dam in various states is approximately equal. But in lower part of the dam, with decrease in stiffness of alluvial foundation vertical and horizontal stresses have been increased.

CONCLUSIONS

Results of static stress-strain analyses for asphaltic core option of Gabric dam provide possibility of studying dam's behavior in sluicing and construction stages. In these studies, the effect of core deformation modulus, stiffness of coarse grain alluvial foundation and removal of fine grain alluvial on principle stresses, principle shear stresses and vertical and horizontal strains have been investigated. Also, vertical stress distribution at the end of construction, vertical and horizontal displacement and horizontal displacements after sluicing have been presented. The following specific conclusions can be drawn from the study:

In various states, horizontal strain values in core elements are less than 1.2%, thus it could be anticipated that after deformation, asphaltic core will remain impermeable.

Regarding obtained shear stresses of core, possibility of shear failure in core elements is low.

By increasing the stiffness of core material, maximum principle stress in all point of core has been increased by increasing the depth that is an indication of more absorption of stress by asphaltic core.

By increase of stiffness of core material, maximum principle shear stress in all point of core has been increased by depth.

By decrease of stiffness, both vertical and horizontal strains have been increased.

Total removal of fine grain alluvial beneath of lower shell has negligible effect on stress and strain values in asphaltic core.

Values of stress and strain after sluicing in upper part of the dam in different stiffness of alluvial foundation were approximately equal, while in lower part with decrease of stiffness of alluvial foundation, maximum principle stresses and maximum shear stresses in asphaltic core elements have been increased.

Vertical and horizontal strain has been increased by decreasing of stiffness of alluvial foundation.

REFERENCES

Adikari, G.S.N., T. Valstad, B. Kjarnsli and K. Hoeg, 1988. Behaviour of storvatn dam, Norway: A case of prediction versus performance. Norges Geotekniske Institutt, 173: 1-8.

Akkose, M., A. Suleyman, A. Bayraktar and A.A. Dumanoglu, 2007. Stochastic seismic response of Keban dam by the finite element method. Applied Math. Comput., 184: 704-714.

Chugh, A.K., 1983. Dynamic response analysis of embankment dams. Engineering and Research Center, Bureau of Reclamation, U.S. Department of the Interior, Denver, Colorado 80225 U.S.A.

Hoeg, K., 1993. Asphaltic Concrete Cores for Embankment Dams. Norwegian Geotecnical Institute, Norway, pp: 88.

ICOLD, 1985. Filling materials for watertight cutoff walls. International Commission on Large Dams, Bulletin 51.

Lefebvre, G. and J.M. Duncan, 1974. Finite element analysis of transverse cracking in low-embankment dams. California Univ Berkeley Office of Research. Accession Number: ADA001523. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA001523.

Moayed, R.Z. and M.F. Ramzanpour, 2008. Seismic behavior of zoned core embankment dam. EJGE, 13: 1-15.

Tanaka, T., 2007. Viscoplasticity of Geomaterials and Finite Element Analysis. In: Soil Stress-Strain Behavior: Measurement, Modeling and Analysis, Ling, H.I., L. Callisto, D, Leshchinsky and J, Koseki (Eds.). Springer, USA., pp: 769–778.

Tancev, L. and G. Kokalanov, 1995. Application of joint elements at finite element analysis of embankment dams. Eng. Sci., 7: 1-8.

Tsompanakis, Y., N.D. Lagaros, P.N. Psarropoulos and E.C. Georgopoulos, 2009. Simulating the seismic response of embankments via artificial neural networks. Adv. Eng. Software, 40: 640-651.

Zhao, C., S. Valliappan and J. Tabatabaie, 1993. Effect of impervious members and reservoir bottom sediment on dynamic response of embankment dams. Soil Dynamics Earthquake Eng., 12: 199-208.